

Across virtually every discipline, computer-aided tools and new technologies are giving images a higher profile—and prompting concern about their proper use

# New Imaging Tools Put the Art Back Into Science

**BOSTON**—The pilot never saw it coming. Flying over the Rocky Mountains on a clear winter day, the DC-8 cargo jet was abruptly shredded by a sudden, invisible storm that tore off an engine and 5 meters of wing. Remarkably, the plane limped to a safe landing.

Terry Clark, a turbulence specialist at the National Center for Atmospheric Research in nearby Boulder, Colorado, was so intrigued by the incident that he pieced together some 100 gigabytes of weather data collected by civilian and military satellites and ground-based instruments on that day—

9 December 1992. But with no easy way to make sense of the information, Clark contacted the center's Don Middleton, an expert on translating raw data into visible images using new high-speed computers.

Turning the data into pictures, the researchers discovered that lingering faint aerosols from the recent eruption of Mount Pinatubo in the Philippines had illuminated long, vertical tubes of turbulence in the atmosphere that likely caused the damage. It was a phenomenon never before even theorized, much less seen. The fruits of their la-

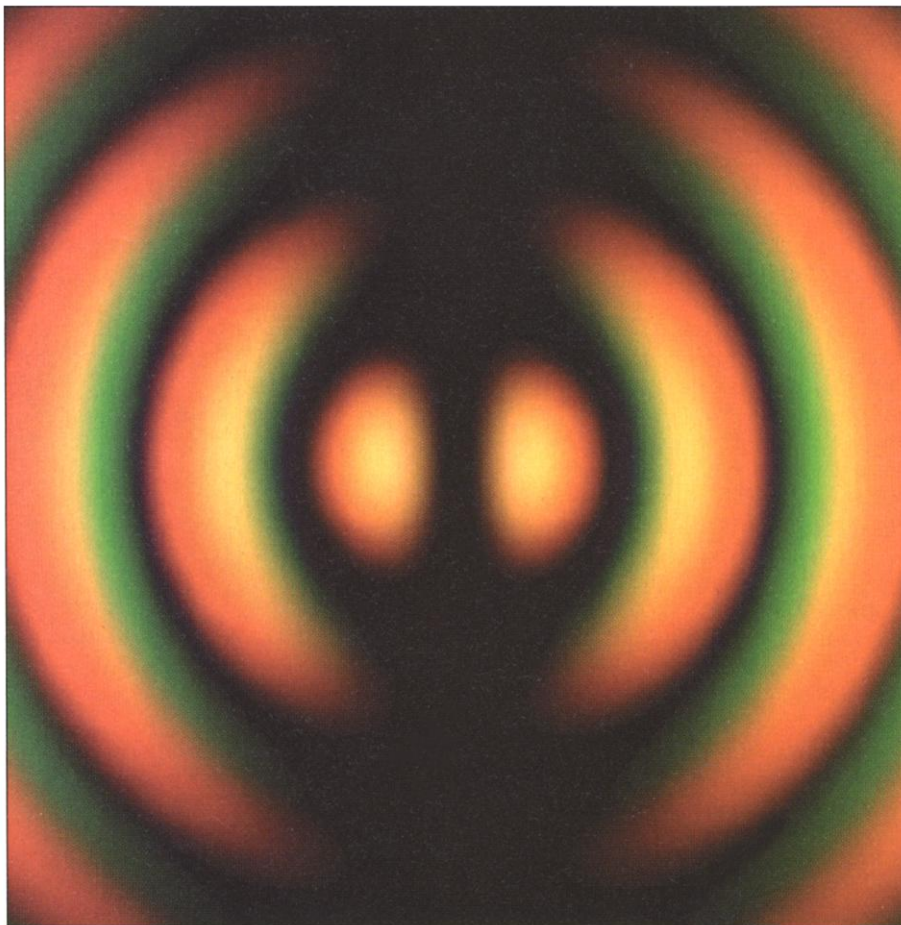
bor appeared last year in the *Journal of Atmospheric Sciences*. "More and more scientists are having trouble understanding their data," says Middleton. "Now we have the computing power to use visualization as an important tool."

Clark and Middleton's collaboration is part of a quiet imaging revolution in the scientific community. Over the past decade, sophisticated and colored digital pictures and movies derived from vast quantities of data have replaced the grainy photographs, dull-gray graphs, and static black-and-white drawings long common in most disciplines. The new tools, often developed for the art and entertainment industries, are becoming common on the lab bench, and access to the Internet has driven down reproduction costs. At the same time, the rising visual flood is raising complex questions about the role of aesthetics in science and the fine line between enhancement and falsification. They also pose a challenge for journal editors, who are wrestling with how best to publish these spectacular images.

Next month the Massachusetts Institute of Technology (MIT) will bring together researchers, publishers, and imagemakers to discuss the promises and pitfalls of imaging in science.\* "This is a high priority for the research infrastructure—as important as broadband Internet or having an SEM [scanning electron microscope] across the street," says Harvard University biochemist George Whitesides, an organizer of the meeting. The National Science Foundation (NSF), a primary sponsor of the conference, stands ready to provide additional funding for imaging projects, promises NSF director Rita Colwell.

## Culture clash

Images have long been an essential part of most disciplines. Galileo interspersed his astronomical writings with drawings of the moons of Jupiter, and detailed anatomical sketches from the Renaissance helped kick-start modern medicine. "Pictures have been



**Quantum model.** A simulation of light passing through two polarizing filters set at right angles and separated by a sheet of film produces interference fringes of various wavelengths. The image demonstrates a host of concepts at once, from quantum measurement and quantum evolution to some aspects of matrix algebra. Such computer modeling is altering the way physical scientists express their understanding of nature.

\* Image and Meaning: Envisioning and Communicating Science and Technology, Cambridge, Massachusetts, 13–16 June. See [web.mit.edu/i-m/image3big.htm](http://web.mit.edu/i-m/image3big.htm)

part of chemistry from the start," says Stanford University chemist Richard Zare.

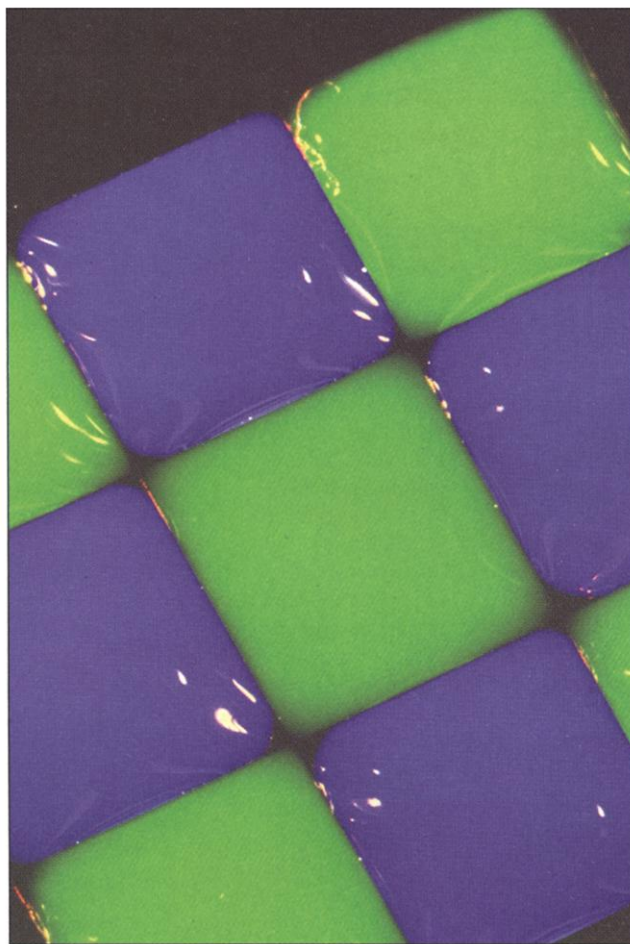
In most fields, however, the word and formula have held sway over the image. "Scientists haven't respected the image as much as they do text," says Felice Frankel, a conference organizer who creates science images at MIT. Adds Don Eigler, a physicist at IBM's Almaden Research Center in San Jose, California, "There is still a certain reluctance to see images as that important." Adding to the resistance is the cost of reproduction—particularly color pictures—in scientific journals and the time, money, and effort involved in creating images.

Computers and new graphic tools are now challenging the traditional superiority of prose and numbers. "The idea of using images used to be considered quite loathsome," recalls Benoit Mandelbrot, a Yale University mathematician who pioneered fractals research in the 1970s. "When I was a child, it was a very nonvisual universe, and people with a sense of the visual were not respected." Mandelbrot recalls how his uncle, a formidable mathematician, took him to Paris museums and painted on weekends yet scoffed at the idea of mixing pictures with math.

As a young researcher, Mandelbrot squelched his visual yearnings until he grew frustrated trying to explain his mathematical reasoning for precipitation models to a collaborating hydrologist. After exploring fractals, he says, "I realized that pictures were essential."

Although his first book on the subject initially received a cold reception, Mandelbrot watched with growing satisfaction as fractals soon became all the rage and visualizing formulas became acceptable. "I was pushing to gain something new," he recalls. "People of the old generation say they'll never forgive me—even my uncle never understood that I made his mathematics alive again."

Computational power has increased exponentially since Mandelbrot's first primitive images, and tools such as Adobe Photoshop are available to virtually every researcher. And because of increases in computing power, scientists now can track cell growth,



**Color coded.** Colored drops of water land on a flat grid of hydrophilic and hydrophobic materials. While spreading across the hydrophilic surface, they stop at hydrophobic gridlines etched at 3-millimeter layers. Careful choice of colors turns an ordinary lab image of a chemical process into an aesthetically pleasing and captivating picture.

weather phenomena, or quantum changes as a natural process rather than as a static set of data. "Now you can watch in real time as data come in—and see something you could not have seen before," says MIT chemist Moungi Bawendi. In Boulder, for example, Middleton recently simulated 48 hours in the life of a hurricane that hit the Carolina coast. The simulation allows researchers to test theories of how storms interact with land. Each frame uses 2 gigabytes of data, crunched by

supercomputers. "Three years ago, this would have been impossible," he says.

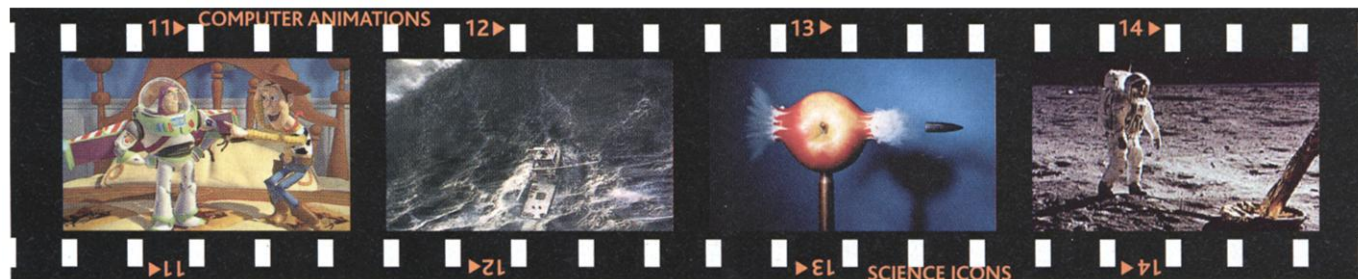
At the Marine Biological Laboratory in Woods Hole, Massachusetts, Shinya Inoue and colleagues worked for 2 years to develop a camera that can monitor cells bathed in polarized light within a centrifuge producing 10,000 times the gravity of Earth. Videos of sea urchin eggs in the centrifuge show their membranes collapsing within 10 seconds of fertilization by a sperm, an intricate effect never before seen so clearly. The findings were published in the March issue of the *Journal of Microscopy*. "Now we can see what we only dreamed about," says Inoue.

Whitesides says these kinds of technological advances, which include the Internet, are essential for progress in cell biology. "There has been no way to talk about time," he says. "And time dependence is one of the next big concepts on the frontier of biology." He foresees Web sites that routinely provide re-

searchers with a movie or the ability to rotate structures. Eigler goes a step further, imagining virtual-reality systems that allow researchers to wander through a cell, a body, or a chemical process. The detail and complexity, he says, would far surpass anything now available.

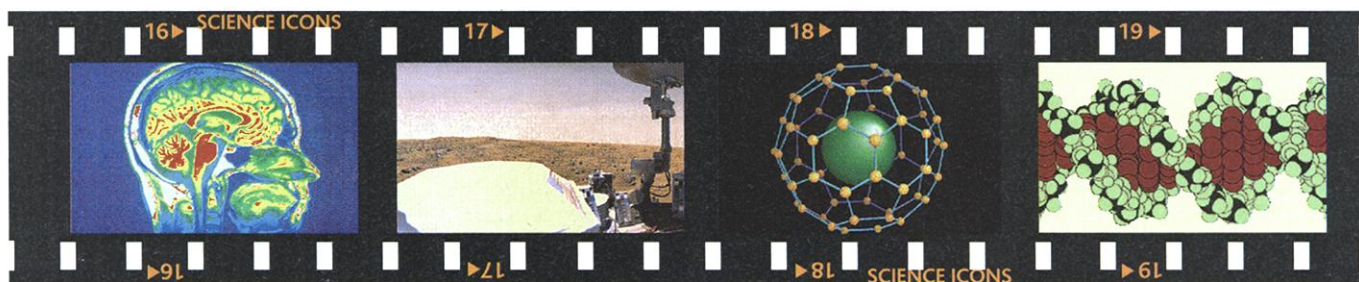
#### Truth telling

But despite the rise of the Web and the promise of color images, virtual reality,



**That's entertainment.** The technology behind Hollywood films like *Toy Story* and *The Perfect Storm* (from left) is already reaching lab benches, with even more advanced systems in the works. More traditional methods such as photography have long served as important research tools and have created a host of unforgettable images in science, from the 1964 picture of a bullet speeding through an apple to U.S. astronauts walking on the lunar surface.





**Inner and outer.** Imaging systems show what's otherwise invisible to the human eye, whether because it is too small or too far away. From left, a magnetic resonance image of a brain, a 1976 picture taken by the Viking spacecraft of a vast martian plain, a buckyball, and the intertwined strands of DNA that have become an icon of biology.

and sophisticated animations, the scientific community remains wedded to print journals. And because of the expense of color reproduction, most journals have been slow to use more vibrant images. "For some journals, you are forced to pay for reproducing images," says Bawendi. "That has to change."

The flood of new technology is increasing the pressure for change. Many of these new tools flow from the entertainment business, which can invest huge sums to produce a single image. The system used for the hit movie *Toy Story*, for example, is now

being used to create visuals in some labs. "But there's no easy way yet to publish an animation," admits John Anderson, a pioneer in the field.

A few years ago, Anderson left academia for Industrial Light and Magic of San Francisco, California, where he produces special effects for the entertainment industry. Drawing on his knowledge of fluid dynamics and computer science, he designed the waves in the recent movie *The Perfect Storm*. The tools, Anderson predicts, are coming soon to a lab near you. "Film demonstrates that what's possible today is practical in 2 years."

In another movie, last year's action-packed *Mission to Mars*, Anderson had the

task of making a giant structure shaped like a face explode realistically. "We used fully turbulent fluid dynamics, but we shot it upside down and backwards," he says. "It's good physics, but grossly out of context."

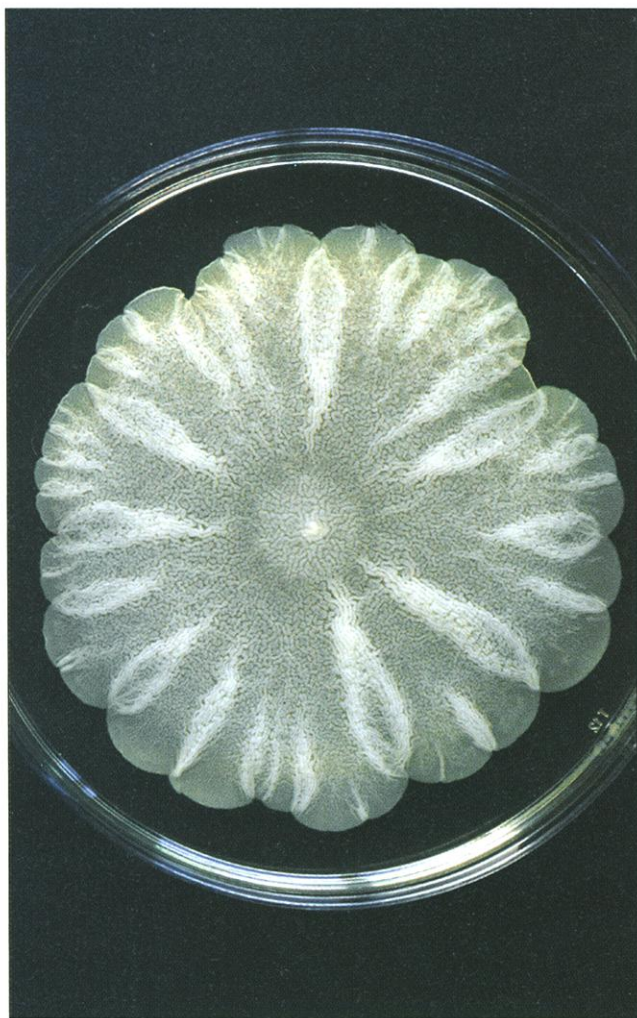
Anderson's job in Hollywood is to produce a realistic, but not necessarily true, image. But his former academic colleagues face a different challenge, he admits: "They must remain credible." Some researchers warn that the easy manipulation of digital images could lead some scientists to take liberties with reality. "I deeply disapprove of people cleaning up an image—it's like taking out the acne [in a picture] of a fashion model," says Whitesides. "Selectively omitting data is not acceptable."

Whitesides would like to see a prestigious body like the National Academy of Sciences review the issue, arguing that "the science community should police itself."

Others say that the rules about proper conduct are already clear and need only to be enforced. "The issues are the same," says Gerald Fink, director of the Whitehead Institute in Cambridge, Massachusetts. "There's a joke going around, that 'Photoshop did this experiment.' There's even a program to straighten bands on gels." Adds IBM's Eigler: "Peer review should remain rigorous; you need to take a good, hard look at the data in an image or a graph."

But determining image truth is tough. "Is the true color of a martian rock how it appears on Mars or on Earth?" asks Peter Smith, a planetary scientist at the University of Arizona in Tucson and principal investigator of the Mars Pathfinder cameras, whose team spent weeks working on the first image planned for public release. Their experience with the 1976 Viking mission had made them cautious: A harried NASA official, wanting to satisfy the pub-

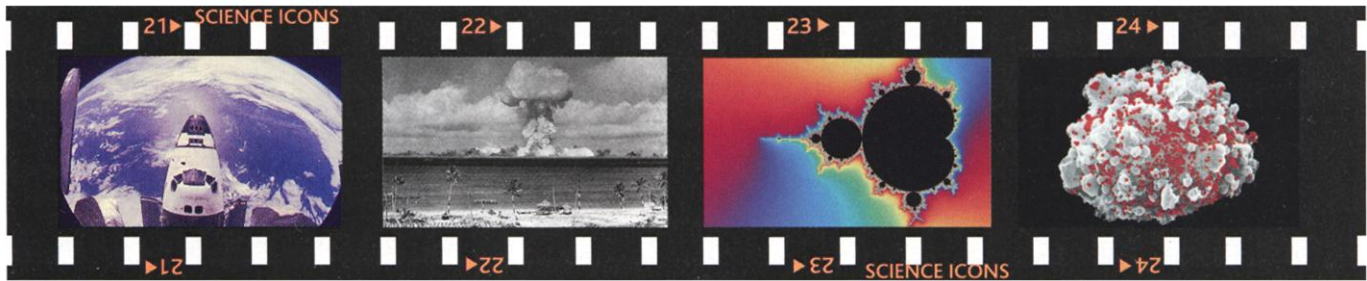
CREDITS: (FILMSTRIP, LEFT TO RIGHT) CNR/PHOTO RESEARCHERS; JPL/NASA; RICHARD E. SMALLEY/RICE UNIVERSITY; (BOTTOM) SOURCE: FELICE FRANKEL



**High impact.** Millions of yeast cells form a floral structure about 7.5 centimeters in diameter when grown on the surface of semisolid media. The petri dish provides a sense of scale but reduces the visual impact of the structure. Balancing the sometimes conflicting needs of science with those of aesthetics involves increasingly difficult choices.







**Reel effects.** Modern images both capture and model reality. From left, the U.S. space shuttle glides above Earth, a hydrogen bomb blast rises above the Pacific, the mathematical concept of fractals is expressed in shape and color, and HIV (in red) attacks a T lymphocyte in this false-color image taken by a scanning electron microscope.

lic's curiosity, released a picture showing a pale blue sky before researchers realized that the martian sky was more a yellowish-brown. "Everybody regretted it, and you can't take it back," says Smith.

As with all experiments, design affects data. Pictures of Mars taken by Viking look very different from those of Pathfinder because of the technology and angles used; the latter mimics humans in the height and placement of the cameras. As a result, the landscape has a very different feel. "There are many ways to interpret reality, and we need many ways to do so," concludes Smith.

One unmistakable sign of the growing appetite for images is the appearance of small companies eager to serve the scientific community. "The tools are becoming so critical that there is a market," says Robert Ezell, who runs Virtual Science in Boston.

### Creativity spur

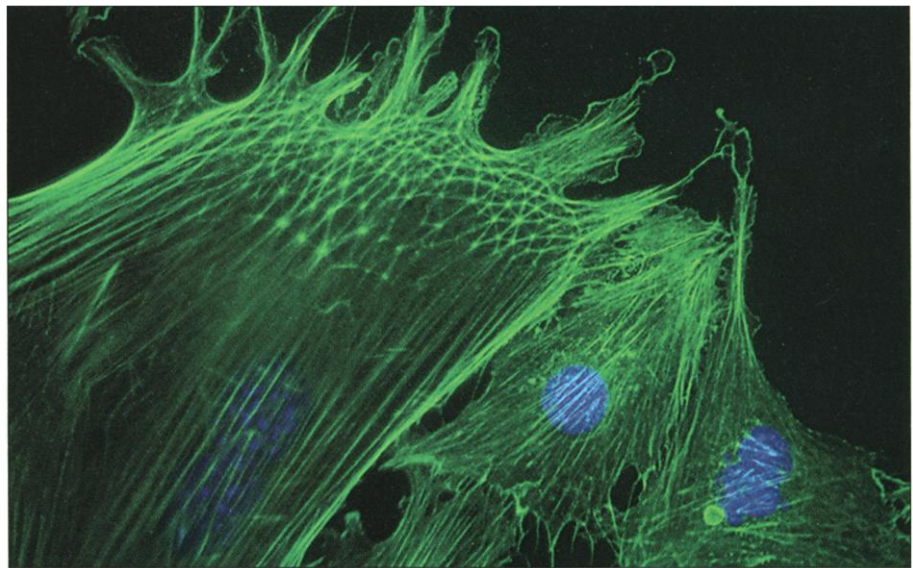
Most researchers agree that images offer important and complementary ways to view reality. Large data sets, such as those used by Clark, can be made manageable, and complex patterns easily spotted. Some scientists go a step further, arguing that an aesthetically pleasing image can spark the curiosity and creativity of viewers unmoved by a set of numbers or page of text.

"Too often, scientific images are based on science-fiction magazines of the 1930s;

there's no sophistication of palette," complains poet and chemist Roald Hoffman of Cornell University in Ithaca, New York. "By using better colors, a scientist can be more

tell you how visual images help, but everyone believes it's true."

Colwell, for one, is a believer. She says that NSF would welcome proposals for a new



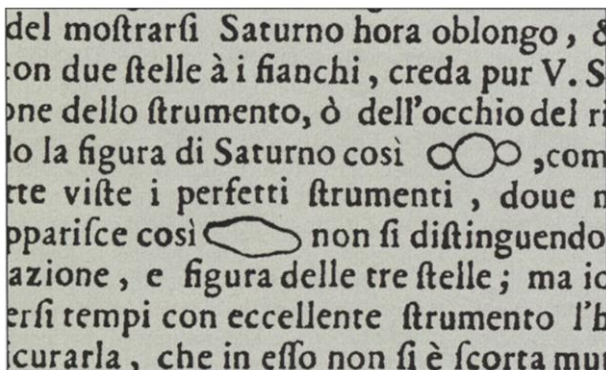
**Inner workings.** New imaging technologies reveal the triangular structure of protein filaments (green) and the location of DNA (blue). Such pictures provide insight into the architecture and processes guiding cellular life.

productive." Adds Whitesides: "Aesthetics add another axis in the design of an experiment. The point is not to make pretty pictures, but to explain the pictures better."

Neuropsychologists say it's impossible to gauge the extent to which images spur scientific creativity, but the idea is gaining credibility. "Images speak to our emotions and our creativity in a way that numbers and equations do not," says Eigler. "Maybe we should pay more attention to the fact that we are not machines." MIT physicist and novelist Alan Lightman adds that "visualizing is very closely connected to the creative process, which remains one of the great mysteries. No one can

center devoted to imaging, and she thinks the benefits of imaging go far beyond enhancing how scientists communicate with the public. "The images offer a way of translating among disciplines, of bridging the gap" between what can be mutually unintelligible jargons. Images, she says, could serve as a kind of Esperanto within the research community. Whitesides and Frankel would like to go a step further. They back a government initiative to pay photographers and graphic designers to work with the nation's laboratories.

Bringing a cadre of artists and designers into the halls of science could be uncomfortable for some researchers. But if words, images, and formulas are truly complementary tools for understanding and explaining natural phenomena, those scientists may have to expand their traditional boundaries. "Neither the word nor the image should be subservient to the other," says Mandelbrot. "Ultimately, they are one." —ANDREW LAWLER



**Come together.** Galileo provided two drawings describing Saturn's strange features, later identified as rings. Such combinations of words and pictures—common in centuries past—are making a comeback today.